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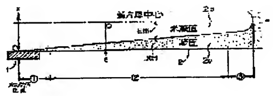
(54) METHOD FOR PREDICTING TEMPERATURE AT UNSOLIDIFIED PART IN CAST SLAB IN CONTINUOUS CASTING

(57)Abstract:
PURPOSE: To simplify the predicting calculation in the solidified condition with a mathematical model, to realize the improvement of accuracy and to predict the light rolling reduction position to a cast slab at high velocity based on the predicting result in the solidified condition in the high accuracy related to a temp. predicting method at unsolidified part in the cast slab, which is suitable to use in order to decide the light rolling reduction position, at the time of executing the light rolling reduction to the cast slab for preventing segregation of impurity elements in the center part of the continuously cast slab.



CONSTITUTION: Then, in a mold part, the solidified condition of the cast slab 2 is obtd. from a difference calculation by applying a heat content-convertion temp. method and in a secondary cooling zone, the solidified thickness X(t) is obtd. by solving a solidifying velocity equation after obtaining the solidifying velocity equation by using the result of the difference calculation and applying a heat balance equation at solid-liquid interface and an intergrating profile method approximating a quadratic equation to the solid phase part temp. The temp. distribution at the unsolidified part 2b is assumed so as to satisfy the prescribed boundary condition equation using this solidifying thickness X(t), and based on the temp. distribution of this unsolidified part 2b, the center temp. of the cast slab 2 is predicted.

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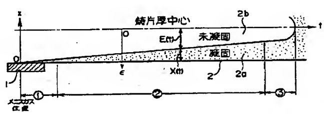
(54)【発明の名称】　連続鋳造における鋳片未凝固部分の温度予測方法



(57)【要約】
【目的】本発明は、連続鋳造鋳片の中心部において不純物元素が偏析するのを防止すべく鋳片に対し軽圧下を行なう際に、該軽圧下位置を決定するために用いて好適の、鋳片未凝固部分の温度予測方法に関し、数式モデルによる凝固状態の予測計算の簡易化，精度の向上を実現し、高い精度の凝固状態予測結果に基づき鋳片に対する軽圧下位置を高速で予測できるようにすることを目的とする。

【構成】そこで、鋳型部分①では含熱量－変換温度法を適用し差分計算により鋳片２の凝固状態を求め、２次冷却帯②，③では、前記差分計算の結果を用い、固液界面での熱バランス式と固相部温度を２次方程式近似する積分プロファイル法とを適用し凝固速度式を求めた後、この凝固速度式を解くことにより凝固厚Ｘ(t)を求め、この凝固厚Ｘ(t)を用いた所定の境界条件式を満足するように、未凝固部分２ｂの温度分布を仮定し、この未凝固部分２ｂの温度分布に基づき鋳片２の中心温度を予測することを特徴とする。

【特許請求の範囲】

【請求項1】　鋳型から鋳片を連続的に引き抜いて鋳造を行なう連続鋳造中に、オンラインで前記鋳片の未凝固部分の温度を予測する方法であって、
凝固初期の前記鋳型部分では、含熱量－変換温度法を適用し差分計算により前記鋳片の凝固状態を求め、
前記鋳片の2次冷却帯では、前記差分計算の結果を用い、固液界面での熱バランス式と固相部温度を2次方程式近似する積分プロファイル法とを適用して前記鋳片の凝固速度式を求めた後、該凝固速度式を解くことにより、前記鋳片の凝固厚を求め、
該凝固厚を用いた所定の境界条件式を満足するように、前記鋳片の未凝固部分の温度分布を仮定し、該未凝固部分の温度分布に基づいて前記鋳片の中心温度を予測することを特徴とする連続鋳造における鋳片未凝固部分の温度予測方法。

【発明の詳細な説明】

【0001】

【産業上の利用分野】本発明は、連続鋳造鋳片の中心部において不純物元素(例えば炭素，マンガン，燐等)が偏析するのを防止すべく鋳片に対し軽圧下を行なう際に、該軽圧下を施すべき位置を決定するために用いて好適の、鋳片未凝固部分の温度予測方法に関する。

【0002】

【従来の技術】一般に、鋳型から鋳片を連続的に引き抜いて鋳造を行なう連続鋳造では、鋳片の厚さ方向中心部が最後に凝固する。この最終凝固部分では、C，Mn，P等の溶鋼成分濃度が高くなり偏析が生じる。

【0003】偏析は強度等の機械的性質のバラツキ要因となるため、このような鋳片の中心偏析を防止する手段として、凝固末期に鋳片を軽圧下し、C，Mn，P等の高濃度溶鋼を鋳片中心部より排除し、均質な鋳片を製造する技術が一般的に行なわれている。

【0004】

【発明が解決しようとする課題】ところで、鋳片圧下を行なう場合、凝固位置，未凝固厚，固相率等の凝固情報に基づいて、圧下条件を適切に選択することが重要になる。しかし、連続鋳造では、トップ，ボトムや鋳造条件の変動があるため、常に凝固状態が変化する。そのような状態変動に対応して動的に圧下制御を行なうべく、オンラインで凝固状態を精度よく予測することが必要となる。

【0005】凝固状態を予測する手段としては、差分計算が一般的に用いられてきているが、差分計算の場合、計算断面に計算節点を設けるため、その処理が膨大になって、計算機負荷の制約によりプロセスコンピュータ等でのオンライン計算が困難になる。逆に、オンライン計算を行なえるように計算節点と計算断面を減らすと、計算精度が大きく低下し、オンライン制御に適用できなくなる。つまり、オンラインで凝固状態を予測し軽圧下制御を行なうためには、計算精度と演算処理の高速化とを同時に満足させる必要がある。

【0006】本発明は、このような課題を解決しようとするもので、数式モデルによる凝固状態の予測計算の簡易化と精度の向上とを実現し、高い精度の凝固状態予測結果に基づいて、鋳片に対する軽圧下位置を高速で予測できるようにした、連続鋳造における鋳片未凝固部分の温度予測方法を提供することを目的とする。

【0007】

【課題を解決するための手段】上記目的を達成するために、本発明の連続鋳造における鋳片未凝固部分の温度予測方法は、鋳型から鋳片を連続的に引き抜いて鋳造を行なう連続鋳造中に、オンラインで前記鋳片の未凝固部分の温度を予測する方法であって、①凝固初期の前記鋳型部分では含熱量－変換温度法を適用し差分計算により前記鋳片の凝固状態を求め、②前記鋳片の2次冷却帯では、前記差分計算の結果を用い、固液界面での熱バランス式と固相部温度を2次方程式近似する積分プロファイル法とを適用して前記鋳片の凝固速度式を求めた後、該凝固速度式を解くことにより、前記鋳片の凝固厚を求め、③該凝固厚を用いた所定の境界条件式を満足するように、前記鋳片の未凝固部分の温度分布を仮定し、該未凝固部分の温度分布に基づいて前記鋳片の中心温度を予測することを特徴としている。

【0008】

【作用】上述した本発明の連続鋳造における鋳片未凝固部分の温度予測方法によれば、凝固初期の鋳型部分では、熱流束の変化が激しいため、含熱量－変換温度法を適用し差分計算により鋳片の凝固状態が求められ、鋳片の2次冷却帯以降では、鋳片の凝固速度の変化が小さくなるので、差分計算の結果を用いながら、固液界面での熱バランス式と固相部温度を2次方程式近似する積分プロファイル法とを適用し、凝固速度式、さらに、この凝固速度式から鋳片の凝固厚が求められる。

【0009】そして、求められた凝固厚を用いた所定の境界条件式を満足するように、鋳片の未凝固部分の温度分布が仮定され、その温度分布に基づき鋳片の中心温度が予測される。

【0010】凝固初期の鋳型部分における極短い区間では、差分計算を行なうために計算断面の数をある程度多く設定する必要はあるが、2次冷却帯以降では、固液界面での熱バランス式と固相部温度を2次方程式近似する積分プロファイル法とを適用することで、数式モデルによる凝固状態の予測計算が簡易化されるとと同時に、十分な予測精度も得られる。

【0011】

【実施例】以下、図面により本発明の一実施例としての連続鋳造における鋳片未凝固部分の温度予測方法について説明すると、図1は本方法を適用される連続鋳造中の鋳片モデルおよびその座標系を示す図であり、この図1

において、１は鋳型、２はこの鋳型１から鉛直下方へ連続的に引き抜かれる鋳片で、この鋳片２は、引抜に伴い徐々に形成されてゆく凝固部分(固相部)２ａと、凝固部分２ａ内方の未凝固部分(液相部)２ｂとを有している。

【００１２】ただし、図１において、鋳型１からの鋳片２の引抜方向が水平に描かれているが、図１の左右方向は鉛直方向に対応し、図１中の右方向が鉛直下方になっている。また、凝固部分２ａの厚さ(凝固厚)は、鋳片２の最外殻位置を０とし鋳片厚中心線(一点鎖線)に直交する方向を正とするｘ軸により表わされ、時刻ｔにおける凝固厚をＸ(t)とする。同様に、未凝固部分２ｂの厚さ(未凝固厚)は、鋳片厚中心位置を０とし鋳片２の最外殻面に直交する方向を正とするε軸により表わされ、時刻ｔにおける未凝固厚をＥ(t)とする。

【００１３】本実施例では、図１に示すように、鋳型１から鋳片２を連続的に引き抜きながら鋳造を行なう連続鋳造中に、オンラインで鋳片２の未凝固部分２ｂの中心温度T_{cnt}を予測して、凝固末期における鋳片２の中心温度に基づいて鋳片２の固相率を知り、鋳片２に対する軽圧下位置を決定しようとするもので、以下に、本発明によるその未凝固部分２ｂの中心温度T_{cnt}の予測手順を説明する。

【００１４】本実施例の数式モデル(凝固厚方程式)について説明する。まず、凝固初期で鋳型１の近傍区間①では、熱流束の変化が激しいため、含熱量－変換温度法による下記(1)式を適用し、差分計算により、鋳片２の凝固状態、つまり鋳片(液相，固相とも)２の温度分布と、凝固厚Ｘとを求める。なお、本実施例においては、区間①の計算に際しては、鋳造速度とメニスカス位置からの距離の関数で熱流束を与えるものとする。

【００１５】

【数１】

$$\rho\frac{dH}{dt}=\lambda_d\frac{d^2\phi}{dx^2}\qquad \phi=\frac{1}{\lambda_d}\int\lambda dT \tag{1}$$

【００１６】ここで、Ｔは温度、Ｈは含熱量、λ_dは基準温度(０℃)における熱伝導率、ϕは変換温度(熱伝導率を温度に変換した物性値)、λは熱伝導率である。

【００１７】そして、区間①での(1)式による差分計算結果を踏まえて、鋳片２の２次冷却帯で凝固速度の変化が小さい区間②では、固液界面(凝固部分２ａと未凝固部分２ｂとの境界面)での熱バランス式と固相部温度を２次方程式近似する積分プロファイル法とを適用している。つまり、固相部(凝固部分)温度T_sを下式(2)に示す２次方程式で仮定し、下式(4)に示す境界条件(固液界面での熱バランス式(3)を用いて、(2)式における各係数Z_0，Z_1，Z_2を下式(4)の通り求める。

【００１８】ここで、固相部温度T_sは、凝固厚，凝固速度，熱伝導率が求められた場合の定常状態の温度分布を表わす。また、区間①での(1)式による差分計算結果である凝固厚Ｘは、熱バランス式(4)における凝固厚Ｘとして代入にされる。

【００１９】(4)式より下式(5)(凝固速度式)が求められ、凝固速度ｄＸ／ｄｔは、凝固厚Ｘの位置で固相温度T_{s1}一定の条件のもと下式(5)で計算される。この(5)式において、Ｃは凝固速度係数で、(5)式での計算値を(1)式に整合させるためのものである。また、凝固厚Ｘの計算精度を高めるため、本実施例では(5)式をRunge-Kutta法により解いて凝固厚Ｘを求める。

【００２０】

$$T_s=Z_2\cdot x^2+Z_1\cdot x+Z_0 \tag{2}$$

【００２１】

【数２】

$$\left.\frac{dT_s}{dx}\right|_{x=0}=\frac{h}{\lambda_s}\left(\left.T_s\right|_{x=0}-T_o\right)\qquad \left.T_s\right|_{x=X}=T_{s1}\qquad \left.\frac{dT_s}{dx}\right|_{x=X}=\frac{L\rho_1}{\lambda_s}\cdot\frac{dX}{dt} \tag{3}$$

$$\begin{aligned}Z_2&=\frac{1}{\lambda_s X(2+B_1X)}\left\{(1+B_1X)L\rho_1\frac{dX}{dt}-h(T_{s1}-T_o)\right\}\\ Z_1&=\frac{L\rho_1}{\lambda_s}\cdot\frac{dX}{dt}-2\lambda_s X Z_2\qquad Z_0=\frac{Z_1}{B_1}+T_o\end{aligned} \tag{4}$$

【００２２】

【数３】

$$\frac{dX}{dt}=\frac{-a_s(1+b_1X)+\sqrt{a_s^2(1+b_1X)^2+2X(2+b_1X)a_s^2(T_{s1}-T_o)h/(L\rho_1)}}{X(2+b_1X)}\cdot C \tag{5}$$

$$b_1=\frac{h}{\lambda_s}\qquad a_s=\frac{\lambda_s}{\rho_s c_{ps}}$$

【0023】ここで、T_{s1} は固相温度、T_0 は冷却側温度(水温)、Lは固相温度 T_{s1} に対する液相含熱量、Cは凝固速度係数、hは鋳片2外表面での熱伝達率〔kcal/(m^2·h·℃)〕、tは時間、c_{ps} は固相比熱、λ_s は固相熱伝導率(kcal/(m·h·℃))、ρ_s は固相比重量、ρ_l は液相比重量、$B_i = h/\lambda_s$ である。なお、二次冷却帯部分(区間②)でのミストについては、例えば、下式(6)に示す熱伝達率hを用いて計算を行なう。

【0024】

【数4】

$$h\Big|_{mist} = 257 \cdot W^{0.82} \cdot Q_a \cdot (1-0.0075 \cdot (T_w - 30)) \left\{ T_s \Big|_{x=0} \right\}^{-0.136} \quad (6)$$

【0025】ここで、Wは冷却水量密度、Q_a は空気流量、T_w は水温、T_s は鋳片2の固相部(凝固部分2a)の温度で、x＝0を付した T_s は、x＝0位置つまり鋳片2の固相部の外表面位置の温度である。

【0026】図1に示す2次冷却帯区間②では、上述した(2)～(6)式を用いて凝固厚Xの演算が行なわれるが、さらに下流側の凝固末期区間③では、鋳片2の両面からの凝固の影響が現れ、凝固厚とともに凝固速度が急速に大きくなる。この現象を数式化するため、下式(7)の形を導入した。ここで、定数Dは、(5),(7)式で得られる凝固速度を一致・整合させるためのものである。また、(5),(7)式中のC，nは、(1)式の差分計算結果と(2)～(7)式の凝固厚方程式による計算結果とを整合させるべく算出されたものである。

【0027】

【数5】

$$\frac{dX}{dt} = \frac{D}{(S_t - X)^n} \quad (7)$$

【0028】ここで、S_t は鋳片2の厚さの2分の1、nは凝固末期凝固速度指数である。

【0029】上述した(2)～(7)式により、区間②，③における鋳片2の凝固速度dX／dt，凝固厚X，鋳片2の表面温度 $T_s(x=0)$ が算出される。なお、鋳片2の表面温度 $T_s(x=0)$ に基づいて、鋳片2の熱伝達率hが求められる。

【0030】さて、鋳片2に対する軽圧下の制御では、鋳片2の未凝固部分2bの中心付近の温度／固相率を知る必要がある。そこで、本実施例では、(2)～(7)式に基づき算出された凝固厚データを用い下式(8)により示すような境界条件式を満足するように、ある時間tにおける未凝固部分2bの温度分布f(ε)を仮定し、この温度分布f(ε)を(9)式に代入して未凝固部分2bの中心温度 T_{cnt} を求める。つまり、(2)～(7)式を用いて凝固厚X(未凝固厚E)，鋳片表面温度，凝固位置での固相部温度勾配，鋳片表面熱伝達率を計算し、これらを下式(8)，(9)に代入して、未凝固部分2bの中心温度 T_{cnt} を求めている。

【0031】

【数6】

$$f(E) = T_{s1} \qquad \frac{df}{d\varepsilon}\Big|_{\varepsilon=0} = 0 \qquad \frac{df}{d\varepsilon}\Big|_{\varepsilon=E} = -\frac{\lambda_s}{\lambda_l} \cdot \frac{dT}{dx}\Big|_{x=X} \quad (8)$$

$$T_{cnt} = \frac{2}{E} \sum_{m=1}^{M} \exp\left(-\frac{a_l \Delta t}{E^2} \alpha_m^2\right) \int_0^E f(\varepsilon) \mathrm{COS}\left(\frac{\varepsilon}{E} \alpha_m\right) d\varepsilon + T_{s1} \quad (9)$$

$$a_l = \frac{\lambda_l}{\rho_l c_{pl}}$$

【0032】ここで、m，Mは次数、Δtは時間増分、c_{pl} は液相比熱、α_m は $\pi/2$, $3\pi/2$, $5\pi/2$, …、ρ_l は液相比重量、λ_l は液相熱伝導率である。なお、上式(9)は、未凝固部分2bに対する熱伝導方程式についてフーリエ級数旧数展開して導出したものである。

【0033】このようにして算出・予測された未凝固部分2bの中心温度 T_{cnt} に基づいて、鋳片2の固相率を知り、鋳片2に対する軽圧下位置が決定される。

【0034】上述のごとく行なわれる本実施例(凝固厚方程式)による計算結果と、含熱量一変換温度法による差分計算結果との比較結果を図3(a)，(b)に示す。なお、この比較計算に際しては、図2に示すような鋳造速度を設定した。つまり、鋳造速度1.62m／分から0.50m／分の変化を時間経過5～11分に与え、凝固厚と未凝固部分2bの中心での固相率の推移とを予測計算した。

【0035】図3(a)，(b)を比較して明らかなように、鋳造速度変化するメニスカス位置からの距離10m

付近および凝固末期においても、両計算による凝固厚はよく一致している。また、未凝固部分２ｂの中心での固相率は、最終凝固位置での変化割合が多少異なるものの、その差はわずか０．０５ほどで、十分にオンラインモデルとして使用できるものである。

【００３６】このように、本実施例の予測方法によれば、凝固初期の鋳型１部分における極短い区間①では、差分計算を行なうために計算断面の数をある程度多く設定する必要はあるが、２次冷却帯以降の区間②，③では、固液界面での熱バランス式と固相部温度を２次方程式近似する積分プロファイル法とを適用することで、数式モデルによる凝固状態の予測計算が大幅に簡易化されるとと同時に、十分な予測精度も得られることが実証され、実機オンラインモデルへの適用性が確認された。従って、高い精度の凝固状態予測結果に基づいて、鋳片２に対する軽圧下位置を高速で且つ精度よく予測できるのである。

【００３７】

【発明の効果】以上詳述したように、本発明の連続鋳造における鋳片未凝固部分の温度予測方法によれば、凝固初期の鋳型部分では、差分計算を行ないながら、２次冷却帯以降では、固液界面での熱バランス式と固相部温度＊を２次方程式近似する積分プロファイル法とを適用することで、数式モデルによる凝固状態の予測計算を大幅に簡易化できるとともに、予測精度を向上でき、鋳片に対する軽圧下位置を高速かつ高精度で予測できる効果がある。

【図面の簡単な説明】

【図１】本発明の一実施例としての連続鋳造における鋳片未凝固部分の温度予測方法をを適用される連続鋳造中の鋳片モデルおよびその座標系を示す図である。

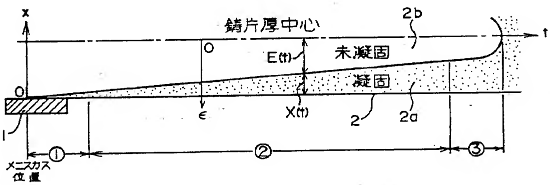
【図２】含熱量－変換温度法による差分計算結果と凝固厚方程式による計算結果との比較に用いた鋳造速度を示すグラフである。

【図３】（ａ）は含熱量－変換温度法による差分計算結果を凝固厚および固相率について示すグラフ、（ｂ）は凝固厚方程式による計算結果を示す凝固厚および固相率について示すグラフである。

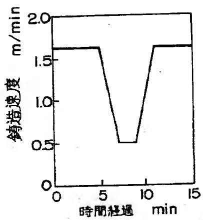
【符号の説明】

１　鋳型
２　鋳片
２ａ　凝固部分（固相部）
２ｂ　未凝固部分（液相部）

【図１】

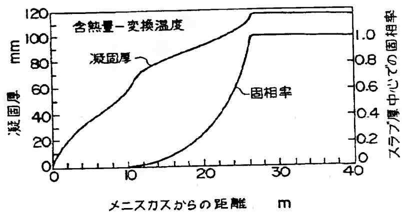


【図2】

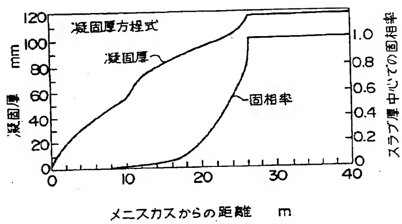

鋳造速度　m/min
2.0
1.5
1.0
0.5
0
0
5
10
15
時間経過　min

【図3】

(a)


含熱量－変換温度
凝固厚
固相率
凝固厚　mm
スラブ厚中心での固相率
120
100
80
60
40
20
0
1.0
0.8
0.6
0.4
0.2
0
0
10
20
30
40
メニスカスからの距離　m

(b)

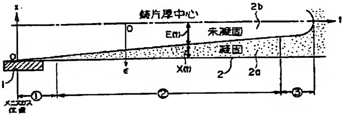

凝固厚方程式
凝固厚
固相率
凝固厚　mm
スラブ厚中心での固相率
120
100
80
60
40
20
0
1.0
0.8
0.6
0.4
0.2
0
0
10
20
30
40
メニスカスからの距離　m

CLAIMS

[Claim(s)]
[Claim 1] It is the approach of predicting the temperature of the non-solidified part of said cast piece on-line during the continuous casting which casts by drawing out a cast piece continuously from mold. In said mold part in early stages of coagulation The coagulation condition of said cast piece is searched for by count. a ******-conversion temperature method -- applying -- difference -- in the secondary cooling zone of said cast piece said difference -- by solving this coagulation rate equation, after asking for the coagulation rate equation of said cast piece with the application of the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface using the result of count The temperature prediction approach of of the cast piece the non-solidified part in the continuous casting characterized by assuming the temperature distribution of the non-solidified part of said cast piece, and predicting the main temperature of said cast piece based on the temperature distribution of this non-solidified part so that it may ask for the coagulation thickness of said cast piece and the predetermined boundary condition type using this coagulation thickness may be satisfied.

[Translation done.]

Drawing selection Representative drawing



[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] In case this invention performs the lightly pressurizing to a cast piece that it should prevent that impurity elements (for example, carbon, manganese, phosphorus, etc.) segregate in the core of a continuous casting cast piece, it is used in order to determine the location which should give this lightly pressurizing one, and relates to the suitable temperature prediction approach of of a cast piece a non-solidified part.
[0002]
[Description of the Prior Art] In the continuous casting which generally casts by drawing out a cast piece continuously from mold, the thickness direction core of a cast piece solidifies at the end. In this last coagulation part, molten steel constituent concentration, such as C, Mn, and P, becomes high, and a segregation arises.
[0003] Since a segregation becomes the variation factor of mechanical characteristics, such as reinforcement, as a means to prevent the main segregation of such a cast piece, the lightly pressurizing [of the cast piece] is carried out to the coagulation last stage, high concentration molten steel, such as C, Mn, and P, is eliminated from a cast piece core, and, generally the technique of manufacturing a homogeneous cast piece is performed.
[0004]
[Problem(s) to be Solved by the Invention] By the way, when performing a cast piece draft, based on coagulation information, such as a solidification position, non-solidified thickness, and a rate of solid phase, it becomes important to choose pressing-down conditions appropriately. However, in continuous casting, since there is fluctuation of the top, a bottom, or casting conditions, a coagulation condition always changes. It is necessary to predict a coagulation condition with a sufficient precision on-line in order to perform draft control dynamically corresponding to such condition fluctuation.
[0005] as a means to predict a coagulation condition -- difference -- although count has generally been used -- difference -- in order to establish a count joint in a count cross section in count, the processing becomes huge and the online count by a process computer etc. becomes difficult by constraint of a computer load. When a count joint and a count cross section are reduced so that online count can be performed, count precision falls greatly and it becomes impossible on the contrary, to apply to online control. That is, in order to predict a coagulation condition on-line and to perform lightly pressurizing control, it is necessary to satisfy count precision and improvement in the speed of data processing to coincidence.
[0006] This invention tends to solve such a technical problem, realizes the simplification of prediction count of a coagulation condition and the improvement in precision by the mathematical model, and aims at offering the temperature prediction approach of of the cast piece the non-solidified part in continuous casting which enabled it to predict the lightly pressurizing location to a cast piece at high speed based on the coagulation state-prediction result of a high precision.
[0007]
[Means for Solving the Problem] In order to attain the above-mentioned purpose, the

temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention It is the approach of predicting the temperature of the non-solidified part of said cast piece on-line during the continuous casting which casts by drawing out a cast piece continuously from mold. ** said mold part in early stages of coagulation — a ******-conversion temperature method — applying — difference — count — the coagulation condition of said cast piece — asking — ** — in the secondary cooling zone of said cast piece said difference — by solving this coagulation rate equation, after asking for the coagulation rate equation of said cast piece with the application of the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface using the result of count The temperature distribution of the non-solidified part of said cast piece are assumed, and it is characterized by predicting the main temperature of said cast piece based on the temperature distribution of this non-solidified part so that it may ask for the coagulation thickness of said cast piece and the predetermined boundary condition type using ** this coagulation thickness may be satisfied.

[0008]

[Function] According to the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention mentioned above, in the mold part in early stages of coagulation The coagulation condition of a cast piece is searched for by count since change of thermal flux is sharp — a ******-conversion temperature method — applying — difference — henceforth [the secondary cooling zone of a cast piece] since change of the coagulation rate of a cast piece becomes small — difference — the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface while using the result of count — applying — a coagulation rate equation — the coagulation thickness of a cast piece is further called for from this coagulation rate equation.

[0009] And the temperature distribution of the non-solidified part of a cast piece are assumed, and the main temperature of a cast piece is predicted based on the temperature distribution so that the predetermined boundary condition type using the called-for coagulation thickness may be satisfied.

[0010] the pole in the mold part in early stages of coagulation — the short section — difference — in order to calculate , it be necessary to set up somewhat many number of count cross sections but , and henceforth [a secondary cooling zone] , it be apply the integral profile method which carry out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface , and if prediction count of the coagulation condition by the mathematical model be simplify simultaneously , sufficient predictability be also obtain .

[0011]

[Example] Hereafter, if a drawing explains the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting as one example of this invention, drawing 1 will be drawing showing the cast piece model under continuous casting to which this approach is applied, and its system of coordinates, and will be set to this drawing 1 . It is the cast piece by which 1 is drawn out to mold and 2 is continuously drawn out from this mold 1 in a vertical lower part, and this cast piece 2 has coagulation partial (solid phase section) 2a gradually formed in connection with drawing out, and non-solidified partial (liquid phase section) 2b of the method of the inside of coagulation partial 2a.

[0012] However, in drawing 1 , although the drawing-out direction of the cast piece 2 from mold 1 is drawn horizontally, the longitudinal direction of drawing 1 corresponds in the direction of a vertical, and the right in drawing 1 has become a vertical lower part. Moreover, the thickness (coagulation thickness) of coagulation partial 2a is expressed by the x axis which makes forward the direction which sets the outermost shell location of a cast piece 2 to 0, and intersects perpendicularly with a cast piece thickness center line (alternate long and short dash line), and sets coagulation thickness in time of day t to X (t). Similarly, the thickness (non-solidified thickness) of non-solidified partial 2b is expressed by epsilon shaft which makes forward the direction which sets a cast piece thickness center position to 0, and intersects perpendicularly

with the outermost shell side of a cast piece 2, and sets non-solidified thickness in time of day t to E (t).
[0013] The main temperature Tcnt of non-solidified partial 2b of a cast piece 2 is predicted on-line during the continuous casting which casts in this example while drawing out a cast piece 2 continuously from mold 1, as shown in drawing 1 . Based on the main temperature of the cast piece 2 in the coagulation last stage, the rate of solid phase of a cast piece 2 tends to be got to know, it is going to determine the lightly pressurizing location to a cast piece 2, and the prediction procedure of the main temperature Tcnt of the non-solidified partial 2b by this invention is explained below.
[0014] The mathematical model (coagulation thickness equation) of this example is explained. first, following the (1) type according to a ******-conversion temperature method at the early stages of coagulation, since change of thermal flux is sharp in near section [of mold 1] ** -- applying -- difference -- it asks for the temperature distribution of the coagulation condition 2 of a cast piece 2, i.e., a cast piece, and the coagulation thickness X by count (the liquid phase and solid phase). In addition, in this example, thermal flux shall be given with the function of the distance from a casting rate and a meniscus location on the occasion of count of section **.
[0015]
[Equation 1]

$$\rho\frac{dH}{dt}=\lambda_d\frac{d^2\phi}{dx^2} \qquad \phi=\frac{1}{\lambda_d}\int\lambda dT \qquad (1)$$

[0016] Here, conversion temperature (physical-properties value which changed thermal conductivity into temperature), and lambda of thermal conductivity [in / ****** and lambdad T and / in H / reference temperature (0 degree C)] and phi are thermal conductivity.
[temperature]
[0017] and the difference by (1) equation in section ** -- based on a count result, change of a coagulation rate has applied the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface (interface of coagulation partial 2a and non-solidified partial 2b) by small section ** with the secondary cooling zone of a cast piece 2. That is, boundary condition which assumes with the secondary equation showing the solid phase section (coagulation part) temperature Ts at a bottom ceremony (2), and is shown in a bottom equation (4) (it asks for each multipliers Z0, Z1, and Z2 in (2) equations using the heat balance equation (3) in a solid-liquid interface as a bottom equation (4).)
[0018] Here, the solid phase section temperature Ts expresses the temperature distribution of a steady state when coagulation thickness, a coagulation rate, and thermal conductivity are called for. moreover, the difference by (1) type in section ** -- coagulation thickness X which it is as a result of count is made substitution as coagulation thickness X in a heat balance type (4).
[0019] (4) a under-from formula type (5) and a (coagulation rate equation) ask -- having -- coagulation rate dX/dt -- the location of the coagulation thickness X -- the solid phase temperature Tsl -- the basis of certain conditions -- it is calculated by the bottom formula (5). In this (5) type, C is a coagulation velocity coefficient and is for making (1) type adjust the calculated value in (5) types. in order [moreover,] to raise the count precision of the coagulation thickness X -- this example -- (5) types -- Runge-Kutta -- it solves by law and asks for the coagulation thickness X.
[0020]
Ts=Z2, x2+Z1, and x+Z0 (2) [0021]
[Equation 2]

$$\frac{dT_s}{dx}\Big|_{x=0}=\frac{h}{\lambda_s}(T_s|_{x=0}-T_o)\quad T_s|_{x=X}=T_{sl}\quad \frac{dT_s}{dx}\Big|_{x=X}=\frac{L\rho_l}{\lambda_s}\cdot\frac{dX}{dt}\quad (3)$$

$$Z_2=\frac{1}{\lambda_s X(2+B_i X)}\{(1+B_i X)L\rho_l\frac{dX}{dt}-h(T_{sl}-T_o)\}$$

$$Z_1=\frac{L\rho_l}{\lambda_s}\cdot\frac{dX}{dt}-2\lambda_s X Z_2\qquad Z_0=\frac{Z_1}{B_i}+T_o\quad (4)$$

[0022]
[Equation 3]

$$\frac{dX}{dt}=\frac{-a_s(1+b_1X)+\sqrt{a_s^2(1+b_1X)^2+2X(2+b_1X)a_s^2(T_{sl}-T_o)h/(L\rho_l)}}{X(2+b_1X)}\cdot C\qquad (5)$$

$$b_1=\frac{h}{\lambda_s}\qquad a_s=\frac{\lambda_s}{\rho_s c_{ps}}$$

[0023] Liquid phase ****** [here as opposed to / Tsl / as opposed to / in solid phase temperature and T0 / cold-end temperature (water temperature) / the solid phase temperature Tsl in L], C — for time amount and cps, the solid phase specific heat and lambdas are [a coagulation velocity coefficient and h / the heat transfer rate [kcal/(m2andh-**)] in cast piece 2 outside surface, and t / solid phase specific weight and rhol of solid phase thermal conductivity (kcal/(m-hand**)) and rhos] liquid phase specific weight and Bi=h/lambdas. In addition, about Myst for a secondary-cooling-of-concrete belt part (section **), it calculates using the heat transfer rate h shown in a bottom type (6), for example.
[0024]
[Equation 4]

$$h\Big|_{mist}=257\cdot W^{0.52}\cdot Q_a\cdot(1-0.0075\cdot(T_w-30))\cdot\left\{T_s\Big|_{x=0}\right\}^{-0.130}\qquad (6)$$

[0025] Here, Ts to which water temperature and Ts of an air flow rate and Tw are [a circulating water flow consistency and Qa] the temperature of the solid phase section (coagulation partial 2a) of a cast piece 2, and W gave x= 0 is the temperature of x= 0 location, i.e., the outside-surface location of the solid phase section of a cast piece 2.
[0026] Although the operation of the coagulation thickness X is performed in secondary cooling zone sections ** shown in drawing 1 using (2) - (6) type mentioned above, further, by coagulation terminal section [of the downstream] **, the effect of the coagulation from both sides of a cast piece 2 appears, and a coagulation rate becomes large quickly with coagulation thickness. In order to mathematize this phenomenon, the form of a bottom type (7) was introduced. Here, a constant D is for it being [the coagulation rate obtained by (5) and (7) formulas] in agreement, and adjusting it. moreover, C in (5) and (7) equations and n — the difference of (1) equation — it is computed in order to adjust a count result and the count result by the coagulation thickness equation of (2) - (7) equation.
[0027]
[Equation 5]

$$\frac{dX}{dt}=\frac{D}{(S_t-X)^n}\qquad (7)$$

[0028] Here, St is 1/2 of the thickness of a cast piece 2, and n is a coagulation terminal coagulation rate characteristic.
[0029] The skin temperature Ts (x= 0) of coagulation rate dX/dt of the cast piece 2 in section

** and **, the coagulation thickness X, and a cast piece 2 is computed by (2) - (7) type mentioned above. In addition, based on the skin temperature Ts (x= 0) of a cast piece 2, the heat transfer rate h of a cast piece 2 is searched for.
[0030] Now, it is necessary to get to know the temperature/rate of solid phase near the core of non-solidified partial 2b of a cast piece 2 in the lightly pressurizing control to a cast piece 2. Then, the temperature distribution f of non-solidified partial 2b in a certain time amount t (epsilon) are assumed, these temperature distribution f (epsilon) are substituted for (9) types, and the main temperature Tcnt of non-solidified partial 2b is searched for so that it may be satisfied with this example of a boundary condition type as shown by the bottom type (8) using the coagulation thickness data computed based on (2) - (7) type. That is, the coagulation thickness X (non-solidified thickness E), cast piece skin temperature, the solid phase section temperature gradient in a solidification position, and a cast piece surface heat transfer rate are calculated using (2) - (7) type, these are substituted for a bottom type (8) and (9), and the main temperature Tcnt of non-solidified partial 2b is searched for.
[0031]
[Equation 6]

$$f(E)=T_{s1} \qquad \left.\frac{df}{d\varepsilon}\right|_{\varepsilon=0}=0 \qquad \left.\frac{df}{d\varepsilon}\right|_{\varepsilon=E}=-\frac{\lambda_s}{\lambda_l}\cdot\left.\frac{dT}{dx}\right|_{x=X} \qquad (8)$$

$$T_{cnt}=\frac{2}{E}\sum_{m=1}^{M}\exp\left(-\frac{a_l \Delta t}{E^2}\alpha_m^2\right)\int_0^E f(\varepsilon)\mathrm{COS}\left(\frac{\varepsilon}{E}\alpha_m\right)d\varepsilon+T_{s1} \qquad (9)$$

$$a_l=\frac{\lambda_l}{\rho_l C_{pl}}$$

[0032] here -- for time increment and cpl, the liquid phase specific heat and alpham are [m and M / a degree and deltat / liquid phase specific weight and lambdal of pi / 2 and 3pi / 5pi / 2 and //2, --, rhol] liquid phase thermal conductivity. In addition, about the heat conduction equation to non-solidified partial 2b, it develops the Fourier-series old number and an upper equation (9) is drawn.
[0033] Thus, based on the main temperature Tcnt of non-solidified partial 2b computed and predicted, the rate of solid phase of a cast piece 2 is got to know, and the lightly pressurizing location to a cast piece 2 is determined.
[0034] the count result by this example (coagulation thickness equation) performed like ****, and the difference by the ******-conversion temperature method -- a comparison result with a count result is shown in drawing 3 (a) and (b). In addition, on the occasion of this comparison count, the casting rate as shown in drawing 2 was set up. That is, 0.50m change for /was given in time amount progress 5 - 11 minutes from a part for 1.62m/in casting rate, and prediction count of the transition of the rate of solid phase in the core of coagulation thickness and non-solidified partial 2b was carried out.
[0035] Drawing 3 (a) and (b) are compared, and also in near the distance of 10m and the coagulation last stage from a meniscus location which carry out casting rate change, the coagulation thickness by both count is well in agreement so that clearly. Moreover, although the rates of solid phase in the core of non-solidified partial 2b differ in the change rate in the last solidification position somewhat, the difference can fully be used as an online model about by only 0.05.
[0036] thus, the pole [according to the prediction approach of this example] in mold 1 part in early stages of coagulation -- short section ** -- difference, although it is necessary to set up somewhat many number of count cross sections in order to calculate By. applying the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface in section [after a secondary

cooling zone] **, and ** When prediction count of the coagulation condition by the mathematical model was simplified sharply simultaneously, it was proved that sufficient predictability was also obtained, and the applicability to a system online model was checked. Therefore, based on the coagulation state-prediction result of a high precision, it is a high speed and the lightly pressurizing location to a cast piece 2 can be predicted with a sufficient precision.

[0037]
[Effect of the Invention] As explained in full detail above, according to the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention, in the mold part in early stages of coagulation difference — henceforth [a secondary cooling zone], calculating While being able to simplify sharply prediction count of the coagulation condition by the mathematical model by applying the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface, predictability can be improved, about the lightly pressurizing location to a cast piece, it is highly precise and there are a high speed and effectiveness which can be predicted.

[Translation done.]

TECHNICAL FIELD

[Industrial Application] In case this invention performs the lightly pressurizing to a cast piece that it should prevent that impurity elements (for example, carbon, manganese, phosphorus, etc.) segregate in the core of a continuous casting cast piece, it is used in order to determine the location which should give this lightly pressurizing one, and relates to the suitable temperature prediction approach of of a cast piece a non-solidified part.

[Translation done.]

PRIOR ART

[Description of the Prior Art] In the continuous casting which generally casts by drawing out a cast piece continuously from mold, the thickness direction core of a cast piece solidifies at the end. In this last coagulation part, molten steel constituent concentration, such as C, Mn, and P, becomes high, and a segregation arises.
[0003] Since a segregation becomes the variation factor of mechanical characteristics, such as reinforcement, as a means to prevent the main segregation of such a cast piece, the lightly pressurizing [of the cast piece] is carried out to the coagulation last stage, high concentration molten steel, such as C, Mn, and P, is eliminated from a cast piece core, and, generally the technique of manufacturing a homogeneous cast piece is performed.

[Translation done.]

EFFECT OF THE INVENTION

[Effect of the Invention] As explained in full detail above, according to the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention, in the mold part in early stages of coagulation difference — henceforth [a secondary cooling zone], calculating While being able to simplify sharply prediction count of the coagulation condition by the mathematical model by applying the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface, predictability can be improved, about the lightly pressurizing location to a cast piece, it is highly precise and there are a high speed and effectiveness which can be predicted.

[Translation done.]

TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] By the way, when performing a cast piece draft, based on coagulation information, such as a solidification position, non-solidified thickness, and a rate of solid phase, it becomes important to choose pressing-down conditions appropriately. However, in continuous casting, since there is fluctuation of the top, a bottom, or casting conditions, a coagulation condition always changes. It is necessary to predict a coagulation condition with a sufficient precision on-line in order to perform draft control dynamically corresponding to such condition fluctuation.
[0005] as a means to predict a coagulation condition — difference — although count has generally been used — difference — in order to establish a count joint in a count cross section in count, the processing becomes huge and the online count by a process computer etc. becomes difficult by constraint of a computer load. When a count joint and a count cross section are reduced so that online count can be performed, count precision falls greatly and it becomes impossible on the contrary, to apply to online control. That is, in order to predict a coagulation condition on-line and to perform lightly pressurizing control, it is necessary to satisfy count precision and improvement in the speed of data processing to coincidence.
[0006] This invention tends to solve such a technical problem, realizes the simplification of prediction count of a coagulation condition and the improvement in precision by the mathematical model, and aims at offering the temperature prediction approach of of the cast piece the non-solidified part in continuous casting which enabled it to predict the lightly pressurizing location to a cast piece at high speed based on the coagulation state-prediction result of a high precision.

[Translation done.]

MEANS

[Means for Solving the Problem] In order to attain the above-mentioned purpose, the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention It is the approach of predicting the temperature of the non-solidified part of said cast piece on-line during the continuous casting which casts by drawing out a cast piece continuously from mold. ** said mold part in early stages of coagulation — a ******-conversion temperature method -- applying — difference — count — the coagulation condition of said cast piece — asking — ** — in the secondary cooling zone of said cast piece said difference — by solving this coagulation rate equation, after asking for the coagulation rate equation of said cast piece with the application of the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface using the result of count The temperature distribution of the non-solidified part of said cast piece are assumed, and it is characterized by predicting the main temperature of said cast piece based on the temperature distribution of this non-solidified part so that it may ask for the coagulation thickness of said cast piece and the predetermined boundary condition type using ** this coagulation thickness may be satisfied.

[Translation done.]

OPERATION

[Function] According to the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention mentioned above, in the mold part in early stages of coagulation The coagulation condition of a cast piece is searched for by count. since change of thermal flux is sharp — a ******-conversion temperature method — applying -- difference — henceforth [the secondary cooling zone of a cast piece] since change of the coagulation rate of a cast piece becomes small — difference — the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface while using the result of count — applying -- a coagulation rate equation — the coagulation thickness of a cast piece is further called for from this coagulation rate equation.
[0009] And the temperature distribution of the non-solidified part of a cast piece are assumed, and the main temperature of a cast piece is predicted based on the temperature distribution so that the predetermined boundary condition type using the called-for coagulation thickness may be satisfied.
[0010] the pole in the mold part in early stages of coagulation — the short section — difference — in order to calculate , it be necessary to set up somewhat many number of count cross sections but , and henceforth [a secondary cooling zone] , it be apply the integral profile method which carry out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface , and if prediction count of the coagulation condition by the mathematical model be simplify simultaneously , sufficient predictability be also obtain .

[Translation done.]

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1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

EXAMPLE

[Example] Hereafter, if a drawing explains the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting as one example of this invention, drawing 1 will be drawing showing the cast piece model under continuous casting to which this approach is applied, and its system of coordinates, and will be set to this drawing 1 . It is the cast piece by which 1 is drawn out to mold and 2 is continuously drawn out from this mold 1 in a vertical lower part, and this cast piece 2 has coagulation partial (solid phase section) 2a gradually formed in connection with drawing out, and non-solidified partial (liquid phase section) 2b of the method of the inside of coagulation partial 2a.
[0012] However, in drawing 1 , although the drawing-out direction of the cast piece 2 from mold 1 is drawn horizontally, the longitudinal direction of drawing 1 corresponds in the direction of a vertical, and the right in drawing 1 has become a vertical lower part. Moreover, the thickness (coagulation thickness) of coagulation partial 2a is expressed by the x axis which makes forward the direction which sets the outermost shell location of a cast piece 2 to 0, and intersects perpendicularly with a cast piece thickness center line (alternate long and short dash line), and sets coagulation thickness in time of day t to X (t). Similarly, the thickness (non-solidified thickness) of non-solidified partial 2b is expressed by epsilon shaft which makes forward the direction which sets a cast piece thickness center position to 0, and intersects perpendicularly with the outermost shell side of a cast piece 2, and sets non-solidified thickness in time of day t to E (t).
[0013] The main temperature Tcnt of non-solidified partial 2b of a cast piece 2 is predicted on-line during the continuous casting which casts in this example while drawing out a cast piece 2 continuously from mold 1, as shown in drawing 1 . Based on the main temperature of the cast piece 2 in the coagulation last stage, the rate of solid phase of a cast piece 2 tends to be got to know, it is going to determine the lightly pressurizing location to a cast piece 2, and the prediction procedure of the main temperature Tcnt of the non-solidified partial 2b by this invention is explained below.
[0014] The mathematical model (coagulation thickness equation) of this example is explained. first, following the (1) type according to a ******-conversion temperature method at the early stages of coagulation, since change of thermal flux is sharp in near section [of mold 1] ** -- applying -- difference -- it asks for the temperature distribution of the coagulation condition 2 of a cast piece 2, i.e., a cast piece, and the coagulation thickness X by count (the liquid phase and solid phase). In addition, in this example, thermal flux shall be given with the function of the distance from a casting rate and a meniscus location on the occasion of count of section **.
[0015]
[Equation 1]

$$\rho \frac{dH}{dt} = \lambda_d \frac{d^2\phi}{dx^2} \qquad \phi = \frac{1}{\lambda_d} \int \lambda dT \qquad (1)$$

[0016] Here, conversion temperature (physical-properties value which changed thermal conductivity into temperature), and lambda of thermal conductivity [in / ****** and lambdad T and / in H / reference temperature (0 degree C)] and phi are thermal conductivity.

[temperature]
[0017] and the difference by (1) equation in section ** — based on a count result, change of a coagulation rate has applied the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface (interface of coagulation partial 2a and non-solidified partial 2b) by small section ** with the secondary cooling zone of a cast piece 2. That is, boundary condition which assumes with the secondary equation showing the solid phase section (coagulation part) temperature Ts at a bottom ceremony (2), and is shown in a bottom equation (4) (it asks for each multipliers Z0, Z1, and Z2 in (2) equations using the heat balance equation (3) in a solid-liquid interface as a bottom equation (4).)
[0018] Here, the solid phase section temperature Ts expresses the temperature distribution of a steady state when coagulation thickness, a coagulation rate, and thermal conductivity are called for. moreover, the difference by (1) type in section ** — coagulation thickness X which it is as a result of count is made substitution as coagulation thickness X in a heat balance type (4).
[0019] (4) a under-from formula type (5) and a (coagulation rate equation) ask — having — coagulation rate dX/dt — the location of the coagulation thickness X — the solid phase temperature Tsl — the basis of certain conditions — it is calculated by the bottom formula (5). In this (5) type, C is a coagulation velocity coefficient and is for making (1) type adjust the calculated value in (5) types. in order [moreover,] to raise the count precision of the coagulation thickness X — this example — (5) types — Runge-Kutta — it solves by law and asks for the coagulation thickness X.
[0020]
Ts=Z2, x2+Z1, and x+Z0 (2) [0021]
[Equation 2]

$$\frac{dT_s}{dx}\Big|_{x=0}=\frac{h}{\lambda_s}(T_s|_{x=0}-T_o)\qquad T_s|_{x=X}=T_{sl}\qquad \frac{dT_s}{dx}\Big|_{x=X}=\frac{L\rho_l}{\lambda_s}\cdot\frac{dX}{dt}\quad(3)$$

$$Z_2=\frac{1}{\lambda_s X(2+B_i X)}\left\{(1+B_i X)L\rho_l\frac{dX}{dt}-h(T_{sl}-T_o)\right\}$$

$$Z_1=\frac{L\rho_l}{\lambda_s}\cdot\frac{dX}{dt}-2\lambda_s X Z_2\qquad Z_o=\frac{Z_1}{B_i}+T_o\qquad(4)$$

[0022]
[Equation 3]

$$\frac{dX}{dt}=\frac{-a_s(1+b_1X)+\sqrt{a_s^2(1+b_1X)^2+2X(2+b_1X)a_s^2(T_{sl}-T_o)h/(L\rho_l)}}{X(2+b_1X)}\cdot C\qquad(5)$$

$$b_1=\frac{h}{\lambda_s}\qquad a_s=\frac{\lambda_s}{\rho_s c_{ps}}$$

[0023] Liquid phase ****** [here as opposed to / Tsl / as opposed to / in solid phase temperature and T0 / cold-end temperature (water temperature) / the solid phase temperature Tsl in L], C — for time amount and cps, the solid phase specific heat and lambdas are [a coagulation velocity coefficient and h / the heat transfer rate [kcal/(m2andh-**)] in cast piece 2 outside surface, and t / solid phase specific weight and rhol of solid phase thermal conductivity (kcal/(m-hand**)) and rhos] liquid phase specific weight and Bi=h/lambdas. In addition, about Myst for a secondary-cooling-of-concrete belt part (section **), it calculates using the heat transfer rate h shown in a bottom type (6), for example.
[0024]
[Equation 4]

$$h\Big|_{mist}=257\cdot W^{0.32}\cdot Q_a\cdot(1-0.0075\cdot(T_w-30))\cdot\left\{T_s\Big|_{x=0}\right\}^{-0.136} \quad (6)$$

[0025] Here, Ts to which water temperature and Ts of an air flow rate and Tw are [a circulating water flow consistency and Qa] the temperature of the solid phase section (coagulation partial 2a) of a cast piece 2, and W gave x= 0 is the temperature of x= 0 location, i.e., the outside-surface location of the solid phase section of a cast piece 2.
[0026] Although the operation of the coagulation thickness X is performed in secondary cooling zone sections ** shown in drawing 1 using (2) - (6) type mentioned above, further, by coagulation terminal section [of the downstream] **, the effect of the coagulation from both sides of a cast piece 2 appears, and a coagulation rate becomes large quickly with coagulation thickness. In order to mathematize this phenomenon, the form of a bottom type (7) was introduced. Here, a constant D is for it being [the coagulation rate obtained by (5) and (7) formulas] in agreement, and adjusting it. moreover, C in (5) and (7) equations and n -- the difference of (1) equation -- it is computed in order to adjust a count result and the count result by the coagulation thickness equation of (2) - (7) equation.
[0027]
[Equation 5]

$$\frac{dX}{dt}=\frac{D}{(S_t-X)^n} \quad (7)$$

[0028] Here, St is 1/2 of the thickness of a cast piece 2, and n is a coagulation terminal coagulation rate characteristic.
[0029] The skin temperature Ts (x= 0) of coagulation rate dX/dt of the cast piece 2 in section ** and **, the coagulation thickness X, and a cast piece 2 is computed by (2) - (7) type mentioned above. In addition, based on the skin temperature Ts (x= 0) of a cast piece 2, the heat transfer rate h of a cast piece 2 is searched for.
[0030] Now, it is necessary to get to know the temperature/rate of solid phase near the core of non-solidified partial 2b of a cast piece 2 in the lightly pressurizing control to a cast piece 2. Then, the temperature distribution f of non-solidified partial 2b in a certain time amount t (epsilon) are assumed, these temperature distribution f (epsilon) are substituted for (9) types, and the main temperature Tcnt of non-solidified partial 2b is searched for so that it may be satisfied with this example of a boundary condition type as shown by the bottom type (8) using the coagulation thickness data computed based on (2) - (7) type. That is, the coagulation thickness X (non-solidified thickness E), cast piece skin temperature, the solid phase section temperature gradient in a solidification position, and a cast piece surface heat transfer rate are calculated using (2) - (7) type, these are substituted for a bottom type (8) and (9), and the main temperature Tcnt of non-solidified partial 2b is searched for.
[0031]
[Equation 6]

$$f(E)=T_{s1} \qquad \frac{df}{d\varepsilon}\Big|_{\varepsilon=0}=0 \qquad \frac{df}{d\varepsilon}\Big|_{\varepsilon=E}=-\frac{\lambda_s}{\lambda_1}\cdot\frac{dT}{dx}\Big|_{x=X} \quad (8)$$

$$T_{cnt}=\frac{2}{E}\sum_{m=1}^{M}\exp\left(\frac{a_1\Delta t}{E^2}\alpha_m^2\right)\int_0^E f(\varepsilon)\cos\left(\frac{\varepsilon}{E}\alpha_m\right)d\varepsilon+T_{s1} \quad (9)$$

$$a_1=\frac{\lambda_1}{\rho_1 c_{p1}}$$

[0032] here -- for time increment and cpl, the liquid phase specific heat and alpham are [m and

M / a degree and deltat / liquid phase specific weight and lambdal of pi / 2 and 3pi / 5pi / 2 and //2, —, rhol] liquid phase thermal conductivity. In addition, about the heat conduction equation to non-solidified partial 2b, it develops the Fourier-series old number and an upper equation (9) is drawn.

[0033] Thus, based on the main temperature Tcnt of non-solidified partial 2b computed and predicted, the rate of solid phase of a cast piece 2 is got to know, and the lightly pressurizing location to a cast piece 2 is determined.

[0034] the count result by this example (coagulation thickness equation) performed like ****, and the difference by the ******-conversion temperature method — a comparison result with a count result is shown in drawing 3 (a) and (b). In addition, on the occasion of this comparison count, the casting rate as shown in drawing 2 was set up. That is, 0.50m change for /was given in time amount progress 5 - 11 minutes from a part for 1.62m/in casting rate, and prediction count of the transition of the rate of solid phase in the core of coagulation thickness and non-solidified partial 2b was carried out.

[0035] Drawing 3 (a) and (b) are compared, and also in near the distance of 10m and the coagulation last stage from a meniscus location which carry out casting rate change, the coagulation thickness by both count is well in agreement so that clearly. Moreover, although the rates of solid phase in the core of non-solidified partial 2b differ in the change rate in the last solidification position somewhat, the difference can fully be used as an online model about by only 0.05.

[0036] thus, the pole [according to the prediction approach of this example] in mold 1 part in early stages of coagulation — short section ** — difference, although it is necessary to set up somewhat many number of count cross sections in order to calculate By applying the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface in section [after a secondary cooling zone] **, and ** When prediction count of the coagulation condition by the mathematical model was simplified sharply simultaneously, it was proved that sufficient predictability was also obtained, and the applicability to a system online model was checked. Therefore, based on the coagulation state-prediction result of a high precision, it is a high speed and the lightly pressurizing location to a cast piece 2 can be predicted with a sufficient precision.

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is drawing showing the cast piece model under continuous casting to which temperature prediction ****** of the cast piece the non-solidified part in the continuous casting as one example of this invention is applied, and its system of coordinates.
[Drawing 2] the difference by the ******-conversion temperature method -- it is the graph which shows the casting rate used for the comparison with a count result and the count result by the coagulation thickness equation.
[Drawing 3] the difference according [(a)] to a ******-conversion temperature method -- the graph which shows a count result about coagulation thickness and the rate of solid phase, and (b) are graphs which show the coagulation thickness and the rate of solid phase which show the count result by the coagulation thickness equation.
[Description of Notations]
1 Mold
2 Cast Piece
2a Coagulation part (solid phase section)
2b A non-solidified part (liquid phase section)

[Translation done.]

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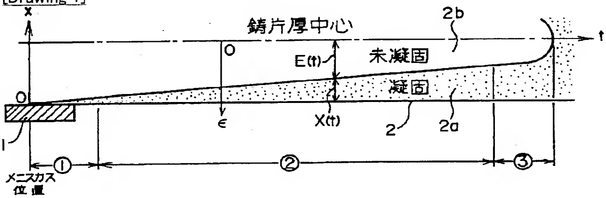
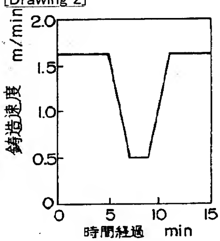
DRAWINGS

[Drawing 1]

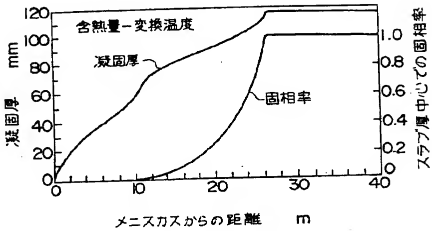


[Drawing 2]

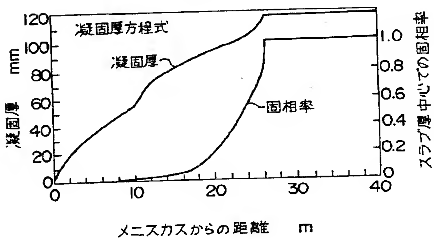


[Drawing 3]

(a)



(b)



[Translation done.]

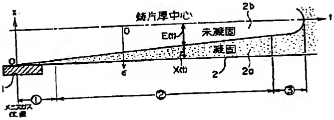
CLAIMS

[Claim(s)]
[Claim 1] It is the approach of predicting the temperature of the non-solidified part of said cast piece on-line during the continuous casting which casts by drawing out a cast piece continuously from mold. In said mold part in early stages of coagulation The coagulation condition of said cast piece is searched for by count. a ******-conversion temperature method -- applying -- difference -- in the secondary cooling zone of said cast piece said difference -- by solving this coagulation rate equation, after asking for the coagulation rate equation of said cast piece with the application of the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface using the result of count The temperature prediction approach of of the cast piece the non-solidified part in the continuous casting characterized by assuming the temperature distribution of the non-solidified part of said cast piece, and predicting the main temperature of said cast piece based on the temperature distribution of this non-solidified part so that it may ask for the coagulation thickness of said cast piece and the predetermined boundary condition type using this coagulation thickness may be satisfied.

[Translation done.]

JP, 05-123842, A [Representative drawing]

Drawing selection Representative drawing



[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Industrial Application] In case this invention performs the lightly pressurizing to a cast piece that it should prevent that impurity elements (for example, carbon, manganese, phosphorus, etc.) segregate in the core of a continuous casting cast piece, it is used in order to determine the location which should give this lightly pressurizing one, and relates to the suitable temperature prediction approach of of a cast piece a non-solidified part.

[0002]

[Description of the Prior Art] In the continuous casting which generally casts by drawing out a cast piece continuously from mold, the thickness direction core of a cast piece solidifies at the end. In this last coagulation part, molten steel constituent concentration, such as C, Mn, and P, becomes high, and a segregation arises.

[0003] Since a segregation becomes the variation factor of mechanical characteristics, such as reinforcement, as a means to prevent the main segregation of such a cast piece, the lightly pressurizing [of the cast piece] is carried out to the coagulation last stage, high concentration molten steel, such as C, Mn, and P, is eliminated from a cast piece core, and, generally the technique of manufacturing a homogeneous cast piece is performed.

[0004]

[Problem(s) to be Solved by the Invention] By the way, when performing a cast piece draft, based on coagulation information, such as a solidification position, non-solidified thickness, and a rate of solid phase, it becomes important to choose pressing-down conditions appropriately. However, in continuous casting, since there is fluctuation of the top, a bottom, or casting conditions, a coagulation condition always changes. It is necessary to predict a coagulation condition with a sufficient precision on-line in order to perform draft control dynamically corresponding to such condition fluctuation.

[0005] as a means to predict a coagulation condition -- difference -- although count has generally been used -- difference -- in order to establish a count joint in a count cross section in count, the processing becomes huge and the online count by a process computer etc. becomes difficult by constraint of a computer load. When a count joint and a count cross section are reduced so that online count can be performed, count precision falls greatly and it becomes impossible on the contrary, to apply to online control. That is, in order to predict a coagulation condition on-line and to perform lightly pressurizing control, it is necessary to satisfy count precision and improvement in the speed of data processing to coincidence.

[0006] This invention tends to solve such a technical problem, realizes the simplification of prediction count of a coagulation condition and the improvement in precision by the mathematical model, and aims at offering the temperature prediction approach of of the cast piece the non-solidified part in continuous casting which enabled it to predict the lightly pressurizing location to a cast piece at high speed based on the coagulation state-prediction result of a high precision.

[0007]

[Means for Solving the Problem] In order to attain the above-mentioned purpose, the

temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention It is the approach of predicting the temperature of the non-solidified part of said cast piece on-line during the continuous casting which casts by drawing out a cast piece continuously from mold. ** said mold part in early stages of coagulation — a ******-conversion temperature method — applying — difference — count — the coagulation condition of said cast piece — asking — ** — in the secondary cooling zone of said cast piece said difference — by solving this coagulation rate equation, after asking for the coagulation rate equation of said cast piece with the application of the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface using the result of count The temperature distribution of the non-solidified part of said cast piece are assumed, and it is characterized by predicting the main temperature of said cast piece based on the temperature distribution of this non-solidified part so that it may ask for the coagulation thickness of said cast piece and the predetermined boundary condition type using ** this coagulation thickness may be satisfied.

[0008]

[Function] According to the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention mentioned above, in the mold part in early stages of coagulation The coagulation condition of a cast piece is searched for by count. since change of thermal flux is sharp — a ******-conversion temperature method — applying — difference — henceforth [the secondary cooling zone of a cast piece] since change of the coagulation rate of a cast piece becomes small — difference — the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface while using the result of count — applying — a coagulation rate equation — the coagulation thickness of a cast piece is further called for from this coagulation rate equation.

[0009] And the temperature distribution of the non-solidified part of a cast piece are assumed, and the main temperature of a cast piece is predicted based on the temperature distribution so that the predetermined boundary condition type using the called-for coagulation thickness may be satisfied.

[0010] the pole in the mold part in early stages of coagulation — the short section — difference — in order to calculate , it be necessary to set up somewhat many number of count cross sections but , and henceforth [a secondary cooling zone] , it be apply the integral profile method which carry out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface , and if prediction count of the coagulation condition by the mathematical model be simplify simultaneously , sufficient predictability be also obtain .

[0011]

[Example] Hereafter, if a drawing explains the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting as one example of this invention, drawing 1 will be drawing showing the cast piece model under continuous casting to which this approach is applied, and its system of coordinates, and will be set to this drawing 1 . It is the cast piece by which 1 is drawn out to mold and 2 is continuously drawn out from this mold 1 in a vertical lower part, and this cast piece 2 has coagulation partial (solid phase section) 2a gradually formed in connection with drawing out, and non-solidified partial (liquid phase section) 2b of the method of the inside of coagulation partial 2a.

[0012] However, in drawing 1 , although the drawing-out direction of the cast piece 2 from mold 1 is drawn horizontally, the longitudinal direction of drawing 1 corresponds in the direction of a vertical, and the right in drawing 1 has become a vertical lower part. Moreover, the thickness (coagulation thickness) of coagulation partial 2a is expressed by the x axis which makes forward the direction which sets the outermost shell location of a cast piece 2 to 0, and intersects perpendicularly with a cast piece thickness center line (alternate long and short dash line), and sets coagulation thickness in time of day t to X (t). Similarly, the thickness (non-solidified thickness) of non-solidified partial 2b is expressed by epsilon shaft which makes forward the direction which sets a cast piece thickness center position to 0, and intersects perpendicularly

with the outermost shell side of a cast piece 2, and sets non-solidified thickness in time of day t to E (t).

[0013] The main temperature Tcnt of non-solidified partial 2b of a cast piece 2 is predicted on-line during the continuous casting which casts in this example while drawing out a cast piece 2 continuously from mold 1, as shown in drawing 1 . Based on the main temperature of the cast piece 2 in the coagulation last stage, the rate of solid phase of a cast piece 2 tends to be got to know, it is going to determine the lightly pressurizing location to a cast piece 2, and the prediction procedure of the main temperature Tcnt of the non-solidified partial 2b by this invention is explained below.

[0014] The mathematical model (coagulation thickness equation) of this example is explained. first, following the (1) type according to a ******-conversion temperature method at the early stages of coagulation, since change of thermal flux is sharp in near section [of mold 1] ** — applying — difference — it asks for the temperature distribution of the coagulation condition 2 of a cast piece 2, i.e., a cast piece, and the coagulation thickness X by count (the liquid phase and solid phase). In addition, in this example, thermal flux shall be given with the function of the distance from a casting rate and a meniscus location on the occasion of count of section **.

[0015]

[Equation 1]

$$\rho\frac{dH}{dt}=\lambda_d\frac{d^2\phi}{dx^2} \qquad \phi=\frac{1}{\lambda_d}\int\lambda dT \qquad (1)$$

[0016] Here, conversion temperature (physical-properties value which changed thermal conductivity into temperature), and lambda of thermal conductivity [in / ****** and lambdad T and / in H / reference temperature (0 degree C)] and phi are thermal conductivity.

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[0017] and the difference by (1) equation in section ** — based on a count result, change of a coagulation rate has applied the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface (interface of coagulation partial 2a and non-solidified partial 2b) by small section ** with the secondary cooling zone of a cast piece 2. That is, boundary condition which assumes with the secondary equation showing the solid phase section (coagulation part) temperature Ts at a bottom ceremony (2), and is shown in a bottom equation (4) (it asks for each multipliers Z0, Z1, and Z2 in (2) equations using the heat balance equation (3) in a solid-liquid interface as a bottom equation (4).)

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[0019] (4) a under-from formula type (5) and a (coagulation rate equation) ask — having — coagulation rate dX/dt — the location of the coagulation thickness X — the solid phase temperature Tsl — the basis of certain conditions — it is calculated by the bottom formula (5). In this (5) type, C is a coagulation velocity coefficient and is for making (1) type adjust the calculated value in (5) types. in order [moreover,] to raise the count precision of the coagulation thickness X — this example — (5) types — Runge-Kutta — it solves by law and asks for the coagulation thickness X.

[0020]

Ts=Z2, x2+Z1, and x+Z0 (2) [0021]

[Equation 2]

$$\left.\frac{dT_s}{dx}\right|_{x=0}=\frac{h}{\lambda_s}\left(T_s|_{x=0}-T_o\right)\quad T_s|_{x=X}=T_{sl}\quad \left.\frac{dT_s}{dx}\right|_{x=X}=\frac{L\rho_l}{\lambda_s}\cdot\frac{dX}{dt} \qquad (3)$$

$$Z_2=\frac{1}{\lambda_s X(2+B_i X)}\left\{(1+B_i X)L\rho_l\frac{dX}{dt}-h(T_{sl}-T_o)\right\}$$

$$Z_1=\frac{L\rho_l}{\lambda_s}\cdot\frac{dX}{dt}-2\lambda_s X Z_2 \qquad Z_0=\frac{Z_1}{B_i}+T_o \qquad (4)$$

[0022]
[Equation 3]

$$\frac{dX}{dt}=\frac{-a_s(1+b_1X)+\sqrt{a_s^2(1+b_1X)^2+2X(2+b_1X)a_s^2(T_{sl}-T_o)h/(L\rho_l)}}{X(2+b_1X)}\cdot C \qquad (5)$$

$$b_1=\frac{h}{\lambda_s} \qquad a_s=\frac{\lambda_s}{\rho_s c_{ps}}$$

[0023] Liquid phase ****** [here as opposed to / Tsl / as opposed to / in solid phase temperature and T0 / cold-end temperature (water temperature) / the solid phase temperature Tsl-in-L], C — for time amount and cps, the solid phase specific heat and lambdas are [a coagulation velocity coefficient and h / the heat transfer rate [kcal/(m2andh-**)] in cast piece 2 outside surface, and t / solid phase specific weight and rhol of solid phase thermal conductivity (kcal/(m-hand**)) and rhos] liquid phase specific weight and Bi=h/lambdas. In addition, about Myst for a secondary-cooling-of-concrete belt part (section **), it calculates using the heat transfer rate h shown in a bottom type (6), for example.
[0024]
[Equation 4]

$$h\Big|_{mist}=257\cdot W^{0.32}\cdot Q_a\cdot(1-0.0075\cdot(T_w-30))\cdot\left\{T_s\Big|_{x=0}\right\}^{-0.136} \qquad (6)$$

[0025] Here, Ts to which water temperature and Ts of an air flow rate and Tw are [a circulating water flow consistency and Qa] the temperature of the solid phase section (coagulation partial 2a) of a cast piece 2, and W gave x= 0 is the temperature of x= 0 location, i.e., the outside-surface location of the solid phase section of a cast piece 2.
[0026] Although the operation of the coagulation thickness X is performed in secondary cooling zone sections ** shown in drawing 1 using (2) - (6) type mentioned above, further, by coagulation terminal section [of the downstream] **, the effect of the coagulation from both sides of a cast piece 2 appears, and a coagulation rate becomes large quickly with coagulation thickness. In order to mathematize this phenomenon, the form of a bottom type (7) was introduced. Here, a constant D is for it being [the coagulation rate obtained by (5) and (7) formulas] in agreement, and adjusting it. moreover, C in (5) and (7) equations and n — the difference of (1) equation — it is computed in order to adjust a count result and the count result by the coagulation thickness equation of (2) - (7) equation.
[0027]
[Equation 5]

$$\frac{dX}{dt}=\frac{D}{(S_t-X)^n} \qquad (7)$$

[0028] Here, St is 1/2 of the thickness of a cast piece 2, and n is a coagulation terminal coagulation rate characteristic.
[0029] The skin temperature Ts (x= 0) of coagulation rate dX/dt of the cast piece 2 in section

** and **, the coagulation thickness X, and a cast piece 2 is computed by (2) - (7) type mentioned above. In addition, based on the skin temperature Ts (x= 0) of a cast piece 2, the heat transfer rate h of a cast piece 2 is searched for.
[0030] Now, it is necessary to get to know the temperature/rate of solid phase near the core of non-solidified partial 2b of a cast piece 2 in the lightly pressurizing control to a cast piece 2. Then, the temperature distribution f of non-solidified partial 2b in a certain time amount t (epsilon) are assumed, these temperature distribution f (epsilon) are substituted for (9) types, and the main temperature Tcnt of non-solidified partial 2b is searched for so that it may be satisfied with this example of a boundary condition type as shown by the bottom type (8) using the coagulation thickness data computed based on (2) - (7) type. That is, the coagulation thickness X (non-solidified thickness E), cast piece skin temperature, the solid phase section temperature gradient in a solidification position, and a cast piece surface heat transfer rate are calculated using (2) - (7) type, these are substituted for a bottom type (8) and (9), and the main temperature Tcnt of non-solidified partial 2b is searched for.
[0031]
[Equation 6]

$$f(E) = T_{s1} \qquad \left.\frac{df}{d\varepsilon}\right|_{\varepsilon=0} = 0 \qquad \left.\frac{df}{d\varepsilon}\right|_{\varepsilon=E} = -\frac{\lambda_s}{\lambda_1}\cdot\left.\frac{dT}{dx}\right|_{x=X} \qquad (8)$$

$$T_{cnt} = \frac{2}{E}\sum_{m=1}^{M}\exp\left(-\frac{a_1\Delta t}{E^2}\alpha_m^2\right)\int_0^E f(\varepsilon)\cos\left(\frac{\varepsilon}{E}\alpha_m\right)d\varepsilon + T_{s1} \qquad (9)$$

$$a_1 = \frac{\lambda_1}{\rho_1 C_{p1}}$$

[0032] here -- for time increment and cpl, the liquid phase specific heat and alpham are [m and M / a degree and deltat / liquid phase specific weight and lambdal of pi / 2 and 3pi / 5pi / 2 and //2, --, rhol] liquid phase thermal conductivity. In addition, about the heat conduction equation to non-solidified partial 2b, it develops the Fourier-series old number and an upper equation (9) is drawn.
[0033] Thus, based on the main temperature Tcnt of non-solidified partial 2b computed and predicted, the rate of solid phase of a cast piece 2 is got to know, and the lightly pressurizing location to a cast piece 2 is determined.
[0034] the count result by this example (coagulation thickness equation) performed like ****, and the difference by the ******-conversion temperature method -- a comparison result with a count result is shown in drawing 3 (a) and (b). In addition, on the occasion of this comparison count, the casting rate as shown in drawing 2 was set up. That is, 0.50m change for /was given in time amount progress 5 - 11 minutes from a part for 1.62m/in casting rate, and prediction count of the transition of the rate of solid phase in the core of coagulation thickness and non-solidified partial 2b was carried out.
[0035] Drawing 3 (a) and (b) are compared, and also in near the distance of 10m and the coagulation last stage from a meniscus location which carry out casting rate change, the coagulation thickness by both count is well in agreement so that clearly. Moreover, although the rates of solid phase in the core of non-solidified partial 2b differ in the change rate in the last solidification position somewhat, the difference can fully be used as an online model about by only 0.05.
[0036] thus, the pole [according to the prediction approach of this example] in mold 1 part in early stages of coagulation -- short section ** -- difference, although it is necessary to set up somewhat many number of count cross sections in order to calculate By applying the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface in section [after a secondary

cooling zone] **, and ** When prediction count of the coagulation condition by the mathematical model was simplified sharply simultaneously, it was proved that sufficient predictability was also obtained, and the applicability to a system online model was checked. Therefore, based on the coagulation state-prediction result of a high precision, it is a high speed and the lightly pressurizing location to a cast piece 2 can be predicted with a sufficient precision.

[0037]
[Effect of the Invention] As explained in full detail above, according to the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention, in the mold part in early stages of coagulation difference — henceforth [a secondary cooling zone], calculating While being able to simplify sharply prediction count of the coagulation condition by the mathematical model by applying the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface, predictability can be improved, about the lightly pressurizing location to a cast piece, it is highly precise and there are a high speed and effectiveness which can be predicted.

[Translation done.]

TECHNICAL FIELD

[Industrial Application] In case this invention performs the lightly pressurizing to a cast piece that it should prevent that impurity elements (for example, carbon, manganese, phosphorus, etc.) segregate in the core of a continuous casting cast piece, it is used in order to determine the location which should give this lightly pressurizing one, and relates to the suitable temperature prediction approach of of a cast piece a non-solidified part.

[Translation done.]

PRIOR ART

[Description of the Prior Art] In the continuous casting which generally casts by drawing out a cast piece continuously from mold, the thickness direction core of a cast piece solidifies at the end. In this last coagulation part, molten steel constituent concentration, such as C, Mn, and P, becomes high, and a segregation arises.
[0003] Since a segregation becomes the variation factor of mechanical characteristics, such as reinforcement, as a means to prevent the main segregation of such a cast piece, the lightly pressurizing [of the cast piece] is carried out to the coagulation last stage, high concentration molten steel, such as C, Mn, and P, is eliminated from a cast piece core, and, generally the technique of manufacturing a homogeneous cast piece is performed.

[Translation done.]

EFFECT OF THE INVENTION

[Effect of the Invention] As explained in full detail above, according to the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention, in the mold part in early stages of coagulation difference — henceforth [a secondary cooling zone], calculating While being able to simplify sharply prediction count of the coagulation condition by the mathematical model by applying the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface, predictability can be improved, about the lightly pressurizing location to a cast piece, it is highly precise and there are a high speed and effectiveness which can be predicted.

[Translation done.]

TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] By the way, when performing a cast piece draft, based on coagulation information, such as a solidification position, non-solidified thickness, and a rate of solid phase, it becomes important to choose pressing-down conditions appropriately. However, in continuous casting, since there is fluctuation of the top, a bottom, or casting conditions, a coagulation condition always changes. It is necessary to predict a coagulation condition with a sufficient precision on-line in order to perform draft control dynamically corresponding to such condition fluctuation.
[0005] as a means to predict a coagulation condition -- difference -- although count has generally been used -- difference -- in order to establish a count joint in a count cross section in count, the processing becomes huge and the online count by a process computer etc. becomes difficult by constraint of a computer load. When a count joint and a count cross section are reduced so that online count can be performed, count precision falls greatly and it becomes impossible on the contrary, to apply to online control. That is, in order to predict a coagulation condition on-line and to perform lightly pressurizing control, it is necessary to satisfy count precision and improvement in the speed of data processing to coincidence.
[0006] This invention tends to solve such a technical problem, realizes the simplification of prediction count of a coagulation condition and the improvement in precision by the mathematical model, and aims at offering the temperature prediction approach of of the cast piece the non-solidified part in continuous casting which enabled it to predict the lightly pressurizing location to a cast piece at high speed based on the coagulation state-prediction result of a high precision.

[Translation done.]

MEANS

[Means for Solving the Problem] In order to attain the above-mentioned purpose, the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention It is the approach of predicting the temperature of the non-solidified part of said cast piece on-line during the continuous casting which casts by drawing out a cast piece continuously from mold. ** said mold part in early stages of coagulation -- a ******-conversion temperature method -- applying -- difference -- count -- the coagulation condition of said cast piece -- asking -- ** -- in the secondary cooling zone of said cast piece said difference -- by solving this coagulation rate equation, after asking for the coagulation rate equation of said cast piece with the application of the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface using the result of count The temperature distribution of the non-solidified part of said cast piece are assumed, and it is characterized by predicting the main temperature of said cast piece based on the temperature distribution of this non-solidified part so that it may ask for the coagulation thickness of said cast piece and the predetermined boundary condition type using ** this coagulation thickness may be satisfied.

[Translation done.]

OPERATION

[Function] According to the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting of this invention mentioned above, in the mold part in early stages of coagulation The coagulation condition of a cast piece is searched for by count. since change of thermal flux is sharp -- a ******-conversion temperature method -- applying -- difference -- henceforth [the secondary cooling zone of a cast piece] since change of the coagulation rate of a cast piece becomes small -- difference -- the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface while using the result of count -- applying -- a coagulation rate equation -- the coagulation thickness of a cast piece is further called for from this coagulation rate equation.
[0009] And the temperature distribution of the non-solidified part of a cast piece are assumed, and the main temperature of a cast piece is predicted based on the temperature distribution so that the predetermined boundary condition type using the called-for coagulation thickness may be satisfied.
[0010] the pole in the mold part in early stages of coagulation -- the short section -- difference -- in order to calculate , it be necessary to set up somewhat many number of count cross sections but , and henceforth [a secondary cooling zone] , it be apply the integral profile method which carry out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface , and if prediction count of the coagulation condition by the mathematical model be simplify simultaneously , sufficient predictability be also obtain .

[Translation done.]

EXAMPLE

[Example] Hereafter, if a drawing explains the temperature prediction approach of of the cast piece the non-solidified part in the continuous casting as one example of this invention, drawing 1 will be drawing showing the cast piece model under continuous casting to which this approach is applied, and its system of coordinates, and will be set to this drawing 1 . It is the cast piece by which 1 is drawn out to mold and 2 is continuously drawn out from this mold 1 in a vertical lower part, and this cast piece 2 has coagulation partial (solid phase section) 2a gradually formed in connection with drawing out, and non-solidified partial (liquid phase section) 2b of the method of the inside of coagulation partial 2a.
[0012] However, in drawing 1 , although the drawing-out direction of the cast piece 2 from mold 1 is drawn horizontally, the longitudinal direction of drawing 1 corresponds in the direction of a vertical, and the right in drawing 1 has become a vertical lower part. Moreover, the thickness (coagulation thickness) of coagulation partial 2a is expressed by the x axis which makes forward the direction which sets the outermost shell location of a cast piece 2 to 0, and intersects perpendicularly with a cast piece thickness center line (alternate long and short dash line), and sets coagulation thickness in time of day t to X (t). Similarly, the thickness (non-solidified thickness) of non-solidified partial 2b is expressed by epsilon shaft which makes forward the direction which sets a cast piece thickness center position to 0, and intersects perpendicularly with the outermost shell side of a cast piece 2, and sets non-solidified thickness in time of day t to E (t).
[0013] The main temperature Tcnt of non-solidified partial 2b of a cast piece 2 is predicted on-line during the continuous casting which casts in this example while drawing out a cast piece 2 continuously from mold 1, as shown in drawing 1 . Based on the main temperature of the cast piece 2 in the coagulation last stage, the rate of solid phase of a cast piece 2 tends to be got to know, it is going to determine the lightly pressurizing location to a cast piece 2, and the prediction procedure of the main temperature Tcnt of the non-solidified partial 2b by this invention is explained below.
[0014] The mathematical model (coagulation thickness equation) of this example is explained. first, following the (1) type according to a ******-conversion temperature method at the early stages of coagulation, since change of thermal flux is sharp in near section [of mold 1] ** -- applying -- difference -- it asks for the temperature distribution of the coagulation condition 2 of a cast piece 2, i.e., a cast piece, and the coagulation thickness X by count (the liquid phase and solid phase). In addition, in this example, thermal flux shall be given with the function of the distance from a casting rate and a meniscus location on the occasion of count of section **.
[0015]
[Equation 1]

$$\rho\frac{dH}{dt}=\lambda_d\frac{d^2\phi}{dx^2} \qquad \phi=\frac{1}{\lambda_d}\int\lambda dT \qquad (1)$$

[0016] Here, conversion temperature (physical-properties value which changed thermal conductivity into temperature), and lambda of thermal conductivity [in / ****** and lambdad T and / in H / reference temperature (0 degree C)] and phi are thermal conductivity.

[temperature]
[0017] and the difference by (1) equation in section ** — based on a count result, change of a coagulation rate has applied the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface (interface of coagulation partial 2a and non-solidified partial 2b) by small section ** with the secondary cooling zone of a cast piece 2. That is, boundary condition which assumes with the secondary equation showing the solid phase section (coagulation part) temperature Ts at a bottom ceremony (2), and is shown in a bottom equation (4) (it asks for each multipliers Z0, Z1, and Z2 in (2) equations using the heat balance equation (3) in a solid-liquid interface as a bottom equation (4).)
[0018] Here, the solid phase section temperature Ts expresses the temperature distribution of a steady state when coagulation thickness, a coagulation rate, and thermal conductivity are called for. moreover, the difference by (1) type in section ** — coagulation thickness X which it is as a result of count is made substitution as coagulation thickness X in a heat balance type (4).
[0019] (4) a under-from formula type (5) and a (coagulation rate equation) ask — having — coagulation rate dX/dt — the location of the coagulation thickness X — the solid phase temperature Tsl — the basis of certain conditions — it is calculated by the bottom formula (5). In this (5) type, C is a coagulation velocity coefficient and is for making (1) type adjust the calculated value in (5) types. in order [moreover,] to raise the count precision of the coagulation thickness X — this example — (5) types — Runge-Kutta — it solves by law and asks for the coagulation thickness X.
[0020]
Ts=Z2, x2+Z1, and x+Z0 (2) [0021]
[Equation 2]

$$\left.\frac{dT_s}{dx}\right|_{x=0}=\frac{h}{\lambda_s}\left(T_s|_{x=0}-T_o\right) \qquad T_s|_{x=X}=T_{sl} \qquad \left.\frac{dT_s}{dx}\right|_{x=X}=\frac{L\rho_l}{\lambda_s}\cdot\frac{dX}{dt} \quad (3)$$

$$Z_2=\frac{1}{\lambda_s X(2+B_i X)}\left\{(1+B_i X)L\rho_l\frac{dX}{dt}-h(T_{sl}-T_o)\right\}$$

$$Z_1=\frac{L\rho_l}{\lambda_s}\cdot\frac{dX}{dt}-2\lambda_s X Z_2 \qquad Z_o=\frac{Z_1}{B_i}+T_o \qquad (4)$$

[0022]
[Equation 3]

$$\frac{dX}{dt}=\frac{-a_s(1+b_1X)+\sqrt{a_s^2(1+b_1X)^2+2X(2+b_1X)a_s^2(T_{sl}-T_o)h/(L\rho_l)}}{X(2+b_1X)}\cdot C \qquad (5)$$

$$b_1=\frac{h}{\lambda_s} \qquad a_s=\frac{\lambda_s}{\rho_s c_{ps}}$$

[0023] Liquid phase ****** [here as opposed to / Tsl / as opposed to / in solid phase temperature and T0 / cold-end temperature (water temperature) / the solid phase temperature Tsl in L], C — for time amount and cps, the solid phase specific heat and lambdas are [a coagulation velocity coefficient and h / the heat transfer rate [kcal/(m2andh-**)] in cast piece 2 outside surface, and t / solid phase specific weight and rhol of solid phase thermal conductivity (kcal/(m-hand**)) and rhos] liquid phase specific weight and Bi=h/lambdas. In addition, about Myst for a secondary-cooling-of-concrete belt part (section **), it calculates using the heat transfer rate h shown in a bottom type (6), for example.
[0024]
[Equation 4]

$$h\Big|_{mist}=257\cdot W^{0.52}\cdot Q_a\cdot(1-0.0075\cdot(T_w-30))\cdot\left\{T_s\Big|_{x=0}\right\}^{-0.136}\qquad(6)$$

[0025] Here, Ts to which water temperature and Ts of an air flow rate and Tw are [a circulating water flow consistency and Qa] the temperature of the solid phase section (coagulation partial 2a) of a cast piece 2, and W gave x= 0 is the temperature of x= 0 location, i.e., the outside-surface location of the solid phase section of a cast piece 2.
[0026] Although the operation of the coagulation thickness X is performed in secondary cooling zone sections ** shown in drawing 1 using (2) - (6) type mentioned above, further, by coagulation terminal section [of the downstream] **, the effect of the coagulation from both sides of a cast piece 2 appears, and a coagulation rate becomes large quickly with coagulation thickness. In order to mathematize this phenomenon, the form of a bottom type (7) was introduced. Here, a constant D is for it being [the coagulation rate obtained by (5) and (7) formulas] in agreement, and adjusting it. moreover, C in (5) and (7) equations and n -- the difference of (1) equation — it is computed in order to adjust a count result and the count result by the coagulation thickness equation of (2) - (7) equation.
[0027]
[Equation 5]

$$\frac{dX}{dt}=\frac{D}{(S_t-X)^n}\qquad(7)$$

[0028] Here, St is 1/2 of the thickness of a cast piece 2, and n is a coagulation terminal coagulation rate characteristic.
[0029] The skin temperature Ts (x= 0) of coagulation rate dX/dt of the cast piece 2 in section ** and **, the coagulation thickness X, and a cast piece 2 is computed by (2) - (7) type mentioned above. In addition, based on the skin temperature Ts (x= 0) of a cast piece 2, the heat transfer rate h of a cast piece 2 is searched for.
[0030] Now, it is necessary to get to know the temperature/rate of solid phase near the core of non-solidified partial 2b of a cast piece 2 in the lightly pressurizing control to a cast piece 2. Then, the temperature distribution f of non-solidified partial 2b in a certain time amount t (epsilon) are assumed, these temperature distribution f (epsilon) are substituted for (9) types, and the main temperature Tcnt of non-solidified partial 2b is searched for so that it may be satisfied with this example of a boundary condition type as shown by the bottom type (8) using the coagulation thickness data computed based on (2) - (7) type. That is, the coagulation thickness X (non-solidified thickness E), cast piece skin temperature, the solid phase section temperature gradient in a solidification position, and a cast piece surface heat transfer rate are calculated using (2) - (7) type, these are substituted for a bottom type (8) and (9), and the main temperature Tcnt of non-solidified partial 2b is searched for.
[0031]
[Equation 6]

$$f(E)=T_{s1}\qquad \frac{df}{d\varepsilon}\Big|_{\varepsilon=0}=0\qquad \frac{df}{d\varepsilon}\Big|_{\varepsilon=E}=-\frac{\lambda_s}{\lambda_l}\cdot\frac{dT}{dx}\Big|_{x=X}\qquad(8)$$

$$T_{cnt}=\frac{2}{E}\sum_{m=1}^{M}\exp\left(\frac{a_l\Delta t}{E^2}\alpha_m^2\right)\int_0^E f(\varepsilon)\mathrm{COS}\left(\frac{\varepsilon}{E}\alpha_m\right)d\varepsilon+T_{s1}\qquad(9)$$

$$a_l=\frac{\lambda_l}{\rho_l C_{pl}}$$

[0032] here -- for time increment and cpl, the liquid phase specific heat and alpham are [m and

M / a degree and deltat / liquid phase specific weight and lambdal of pi / 2 and 3pi / 5pi / 2 and //2, —, rhol] liquid phase thermal conductivity. In addition, about the heat conduction equation to non-solidified partial 2b, it develops the Fourier-series old number and an upper equation (9) is drawn.

[0033] Thus, based on the main temperature Tcnt of non-solidified partial 2b computed and predicted, the rate of solid phase of a cast piece 2 is got to know, and the lightly pressurizing location to a cast piece 2 is determined.

[0034] the count result by this example (coagulation thickness equation) performed like ****, and the difference by the ******-conversion temperature method — a comparison result with a count result is shown in drawing 3 (a) and (b). In addition, on the occasion of this comparison count, the casting rate as shown in drawing 2 was set up. That is, 0.50m change for /was given in time amount progress 5 - 11 minutes from a part for 1.62m/in casting rate, and prediction count of the transition of the rate of solid phase in the core of coagulation thickness and non-solidified partial 2b was carried out.

[0035] Drawing 3 (a) and (b) are compared, and also in near the distance of 10m and the coagulation last stage from a meniscus location which carry out casting rate change, the coagulation thickness by both count is well in agreement so that clearly. Moreover, although the rates of solid phase in the core of non-solidified partial 2b differ in the change rate in the last solidification position somewhat, the difference can fully be used as an online model about by only 0.05.

[0036] thus, the pole [according to the prediction approach of this example] in mold 1 part in early stages of coagulation — short section ** — difference, although it is necessary to set up somewhat many number of count cross sections in order to calculate By applying the integral profile method which carries out secondary equation approximation of the heat balance equation and solid phase section temperature in a solid-liquid interface in section [after a secondary cooling zone] **, and ** When prediction count of the coagulation condition by the mathematical model was simplified sharply simultaneously, it was proved that sufficient predictability was also obtained, and the applicability to a system online model was checked. Therefore, based on the coagulation state-prediction result of a high precision, it is a high speed and the lightly pressurizing location to a cast piece 2 can be predicted with a sufficient precision.

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is drawing showing the cast piece model under continuous casting to which temperature prediction ****** of the cast piece the non-solidified part in the continuous casting as one example of this invention is applied, and its system of coordinates.
[Drawing 2] the difference by the ******-conversion temperature method -- it is the graph which shows the casting rate used for the comparison with a count result and the count result by the coagulation thickness equation.
[Drawing 3] the difference according [(a)] to a ******-conversion temperature method -- the graph which shows a count result about coagulation thickness and the rate of solid phase, and (b) are graphs which show the coagulation thickness and the rate of solid phase which show the count result by the coagulation thickness equation.
[Description of Notations]
1 Mold
2 Cast Piece
2a Coagulation part (solid phase section)
2b A non-solidified part (liquid phase section)

[Translation done.]

* NOTICES *

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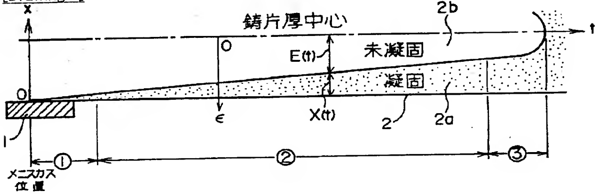
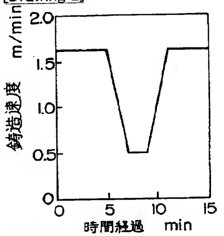
1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

DRAWINGS

[Drawing 1]

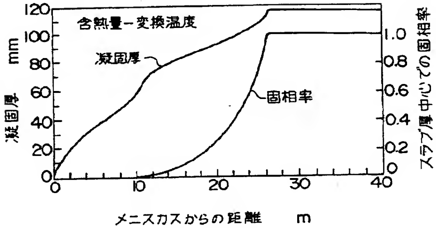


[Drawing 2]

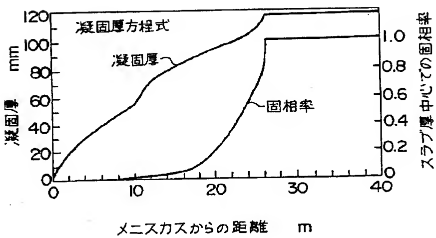


[Drawing 3]

(a)



(b)



[Translation done.]